

*“Erosion modeling of NSTX
Module-A and mixed solid
material PFC’s ”*

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Tasks

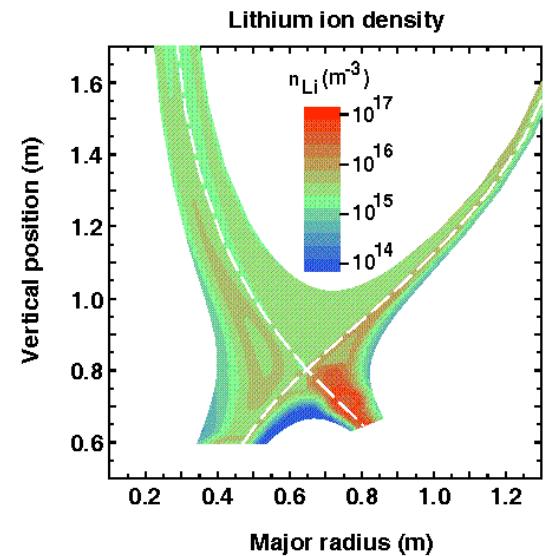
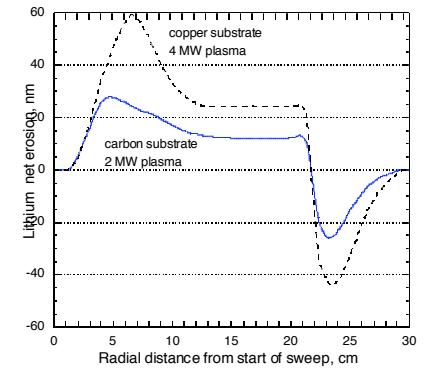
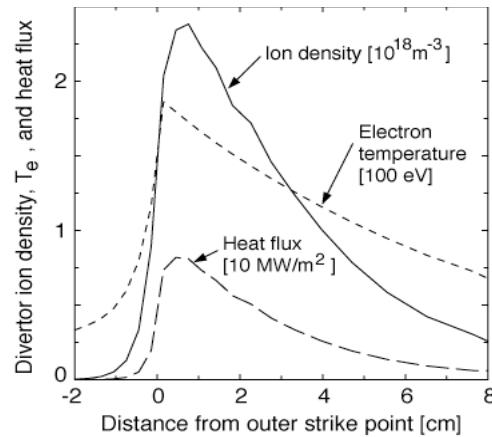
- Update erosion redeposition analysis of NSTX Module-A.
- Initiate analysis of ITER mixed material (Be/C/W) PFC response.
- Supporting science: PISCES mixed-material experiments modeling.

NSTX Module-A Critical Plasma Surface Interaction Issues

- D⁺ pumping by the lithium.
- Edge/SOL plasma low-recycle plasma parameters.
- Power handling capability of Li on substrate.
- Erosion/redeposition--sputter net erosion, core plasma contamination, Li transport to other surfaces.
-

Perform updated erosion/redeposition analysis of NSTX Module-A lithium divertor

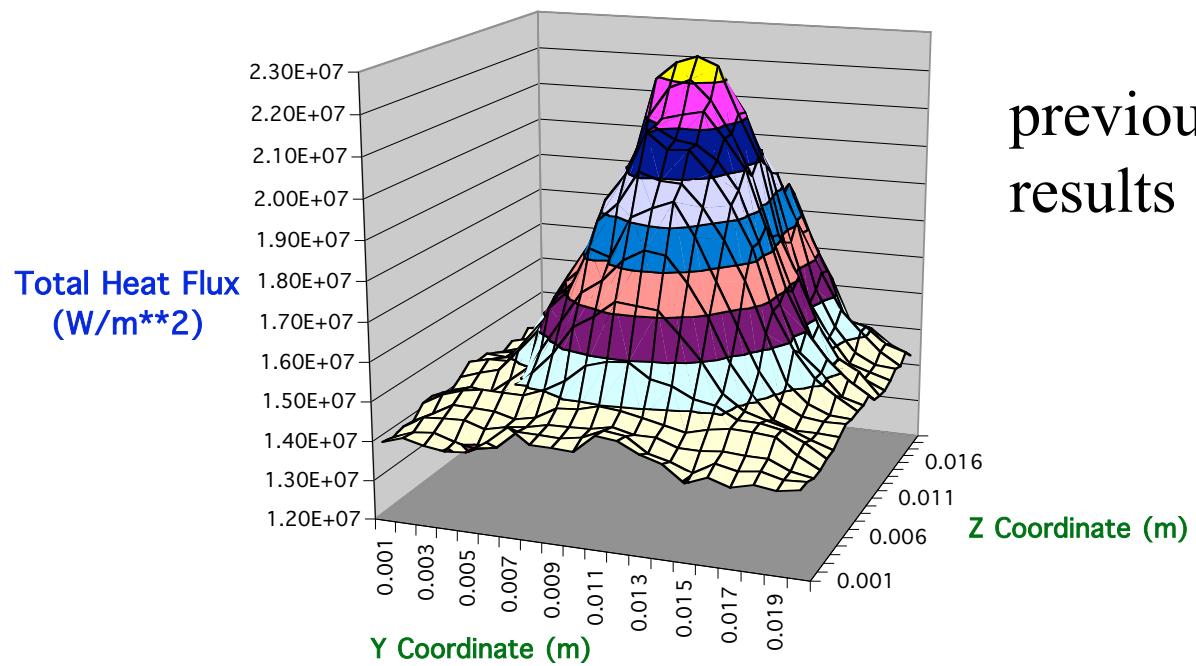
- Following plan of initial study*, use REDEP/WBC code package with UEDGE (Rognlien) plasma SOL parameters, thermal code results with Li/substrate/C tri-material properties (Maingi), and temp.-dependent sputter yield data/model, to predict sputtered Li currents to the wall and plasma, D⁺ pumping capability, Li divertor erosion/growth. **Assess effect of candidate divertor substrate materials, sweep rates, plasma heating power, on surface response and power handling capability.** For Module-A “Phase-1”, “Phase-2”.
- **Assess surface temperature upper limit based on evaporation/sheath response (BPHI-3D code).**



*J.N Brooks, J.P. Allain, T. Rognlien, R. Maingi, PSI-16, J. Nuc. Mat. tbp.

Update NSTX sheath/superheat analysis--with new Te, Ne conditions, Li ionization rates

BPHI-3D Analysis: Lithium NSTX Module with 1 cm dia. circle hot-spot
Deuterium plasma, Te = 80 ev, Ti = 40 ev, Ts = 540 °C, B = 0.5 T, Ne=1.e19 m⁻³, theta = 13 °, G = 0.25



previous superheat results

Initiate analysis of mixed material PFC erosion/redeposition performance for ITER

Tritium codeposition estimates (FIRE)

- Key issue is the effect of wall-sputtered and transported beryllium on carbon (or tungsten) divertor erosion and tritium codeposition. Steps (2 yr goal):
 - a) Develop beryllium ion flux estimate to divertor from ITER Be wall sputtering and scrape-off-layer transport (extrapolation from FIRE results plus relevant ITER results).
 - b) Mixed material code analysis of Be/C mixing/sputtering on the ITER vertical divertor target.
 - c) REDEP/WBC code analysis of erosion/redeposition, and surface-temperature dependent tritium codeposition in resulting growth layers of beryllium and carbon w/ inputs of oxygen flux to divertor and Q/Be and Q/Be-O codeposition rates.

D-T ion flux to wall transport assumption	Q/Be trapping data assumption	Codeposition rate	No. of 20 second shots needed to reach 1 gT
w i t h convection	Mayer et al. (“abundant” oxygen)	9.68 mgT/s	5 shots
“	Causey et al. (low/no oxygen)	1.61 mgT/s	31
diffusion only	Mayer et al. (“abundant” oxygen)	0.542 mgT/s	92
“	Causey et al. (low/no oxygen)	0.0903 mgT/s	554

Mixed material surface evolution models

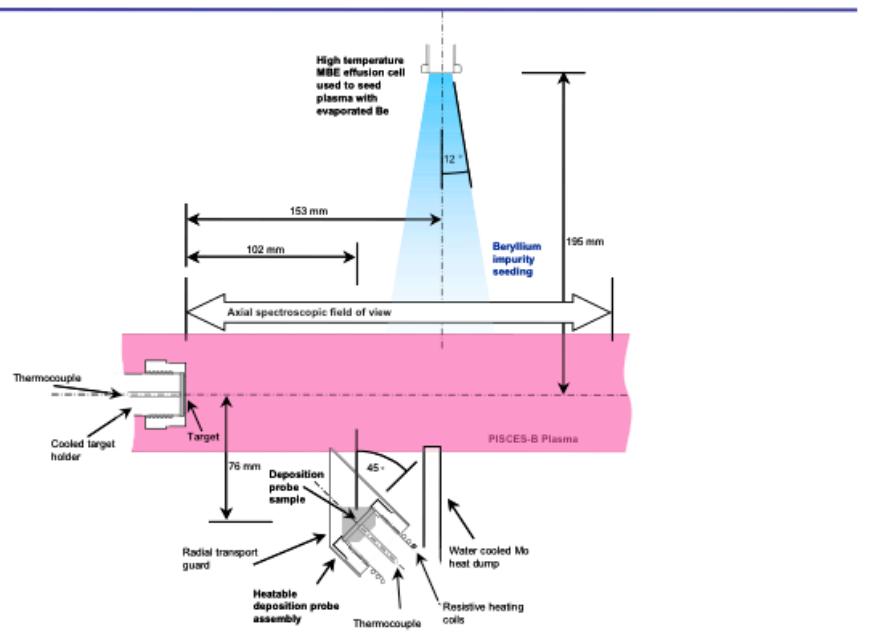
- linear mixing model (0^{th} order)
- binary collision approximation (BCA)
codes with kinetic add-on
- full kinetic
- molecular dynamic

BCA with kinetic add-on

- Method of Yacout & Hassanein (“**Modeling and Analysis of Mixed-Material Surface Evolution and Sputtering**”, **PSI-16**, J. Nuc. Mat. tbp.)
- Codes: ITMC (Monte Carlo/binary-collision) + ITHINK (kinetic/surface-mixing)
- Time-dependent surface composition and sputtering

Modeling of PISCES mixed material, Be/C, experiment

PISCES-B has been modified to allow exposure of samples to Be seeded plasma



R. Doerner, Nov. 2003
PFC Meeting, Oakbrook, IL. 

Modeling of PISCES beryllium seeded mixed-material experiment

- REDEP/WBC code simulation of 2.1 cm diameter carbon target bombarded by $T_e = 5$ eV, Be-seeded multispecies deuterium plasma. Key inputs from TRIM-SP code.
- $T_e = 5$ eV, $T_i = 3$ eV uniform in plasma. $N_e = 3.0 \times 10^{18} \text{ m}^{-3}$ at target center, uniform over target radially, radial variations (past-target) and axial variations in N_e per PISCES data.
- Pre-sheath field, radial diffusion coeff. per previous work (D.G. Whyte et al., Nuclear Fusion 41(2001)47.). Plasma Mach number varies from 1.0 at target to 0.2 at 20 cm axially from target.
- Be/plasma-electron/ion collisions from full kinetic theory. Ion mass = 2.0 AMU in collision routine (corrections for D_2 , D_3 mass should make 2nd order difference).

PISCES modeling, continued

- Be/background-neutral collisions (elastic) using 5 mtorr D_2 @ rt.
- Be atoms launched from points on the target per incident D^+ , D_2^+ , D_3^+ flux profile, with velocity per results of TRIM-SP runs w/ 40 eV D^+ normal incidence on Beryllium-Carbide.
- Detailed Be-I photon emission diagnostic simulated.
- ADAS rate coefficients (per T. Evans GA) for electron-impact ionization of Be-I, Be-II, at 5 eV, at $N_e = 2.5 \times 10^{18} \text{ m}^{-3}$.
 - BeI->BeII, $\langle\sigma v\rangle = 1.428 \times 10^{-14} \text{ m}^3/\text{s}$
 - BeII->BeIII, $\langle\sigma v\rangle = 5.171 \times 10^{-16} \text{ m}^3/\text{s}$

Table 1 WBC analysis of transport of sputtered Be from Be-C target; selected results.
 (100,000 histories, run date 11/1/04)

Parameter	Value
Be atom mean free path, perp. to surface*	3.00 cm
Fraction of sputtered atoms ionized within target plasma	0.370
Fraction of sputtered atoms redeposited as ions on target	0.112
Fraction of sputtered atoms redeposited as atoms on target	0.0064
Incident elevation angle**	8.1 °
Charge state **	1.02
Energy***	56 eV

* for atoms ionized within target plasma

** average for redeposited ions

*** w/ 40 eV bias, WBC standard model-- needs consistency adjustment with PISCES condition for this biasing condition.

0th order beryllium surface composition model

A. Net deposited beryllium flux to sample:

$$\Gamma_{Be} = \Gamma_i \left[f_{Be} - Y^{eff} K_{Be} \frac{(1-f_r)}{(1-Y_z f_r)} \right] \quad (1)$$

where,

Γ_i = ion flux to sample

f_{Be} = beryllium source fraction in plasma

Y^{eff} = effective sputtering coefficient for plasma ions

K_{Be} = beryllium fraction of sample surface

f_r = redeposition fraction for sputtered Be

Y_z = self-sputtering coefficient of redeposited Be

at equilibrium $\Gamma_{Be} = 0$ and/or $K_{Be}=1$. For $Y_z f_r \ll 1$ we get:

$$K_{Be} = \text{Max}\{ f_{Be}/[Y^{eff}(1-f_r)], 1 \} \quad (2)$$

PISCES D ion composition and sputter yields (TRIM-SP)

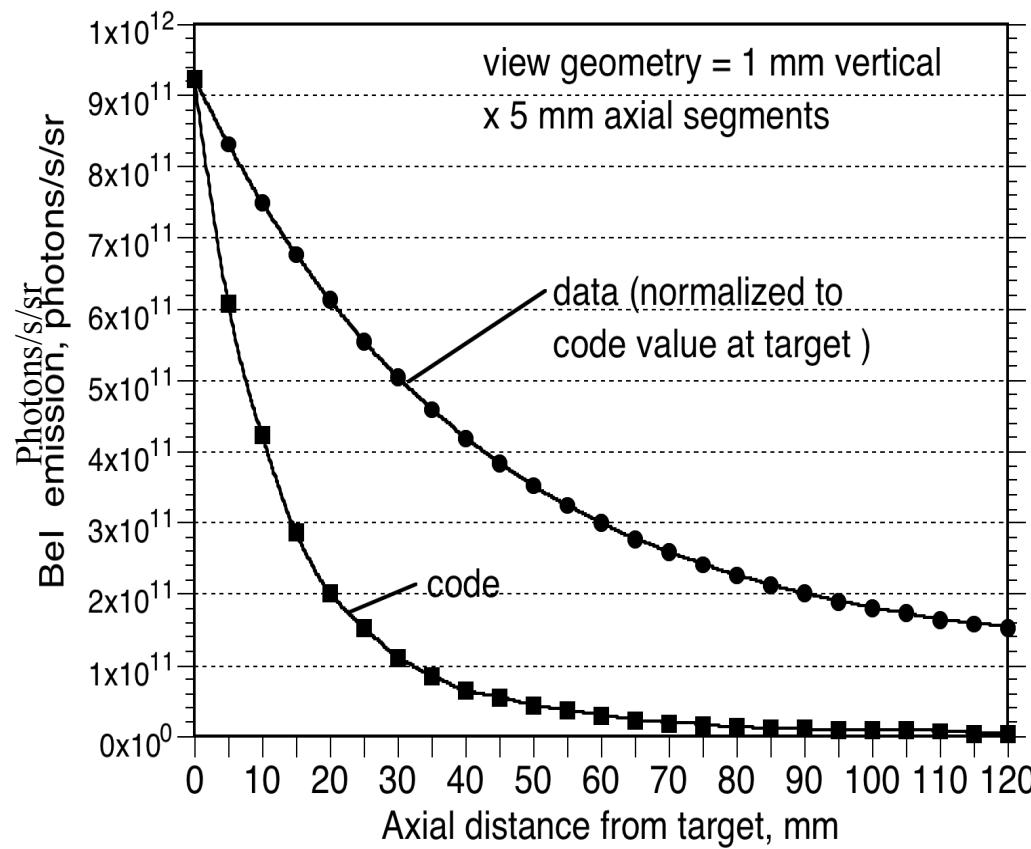
Plasma Species	Ion fraction	Sputter Yield* pure Be target	Sputter Yield* Be-C target
D^+	55%	0.0071	0.0025
D_2^+	25%	0.0040	0.0019
D_3^+	20%	0.0012	0.0006

*Be/ion, normal incidence ions, at 40 eV

for beryllium-carbide
 $K_{Be} \approx 100\%$ Be surface coverage
(agrees with data)

PISCES PHOTON DIAGNOSTIC SIMULATION

PISCES Be sputtering experiment- WBC computed
Bel photon emission axial dependence 11/1/04
(sample dia. = 2.2 cm, Te = 5 eV, shot#4037)



PISCES photon diagnostic simulation, cont.

- Major code/data discrepancy exists for fall-off of photon signal with axial distance.
- UCSD is checking:
 - Absolute* value of code results, i.e., $\sim 1 \times 10^{12}$ photons/s/sr.
 - T_e profile, and other plasma parameters.

Conclusions

- Integrated plasma surface interaction analysis continuing for NSTX Module A (ANL, LLNL, ORNL). (Many issues similar for Module B)
- Mixed material ITER analysis initiated.
- PISCES Be seeded mixed material modeling and code/data comparison (ANL/UCSD) underway.